Renormgroup origin and analysis of Split Higgsino scenario

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Abstract

We present a renormalization group motivation of scale hierarchies in SUSY $SU(5)$ model. The Split Higgsino scenario with a high scale of the SUSY breaking is considered in detail. Its manifestations in experiments are discussed.

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I. INTRODUCTION

Supersymmetric generalization of the SM permits one to solve some inner problems of the theory. However, the MSSM is an ambiguous model: despite the defined set of physical fields, only one characteristic MSSM parameter – electroweak scale M_{EW} – has been fixed in experiment. The scales of scalar quarks and leptons M_0, gaugino $M_{1/2}$, and Higgsino μ, can be picked out as arbitrary ones. Expectations of new dynamical effects of the supersymmetry at the LHC are induced in the MSSM by some specific choice of the SUSY breaking scale that is not very far from the EW scale, $M_{SUSY} \sim M_{1/2} \sim M_0 \sim O\,(1\text{ TeV})$. This scale hierarchy seems "natural", providing regularization of quadratic divergencies long before M_{GUT}. Thus, the MSSM as it is motivated by some theoretical and phenomenological arguments – successful RG evolution, "natural" choice of the renormalization scale and the reasonable dark matter (DM) description – works well for the specific choice of the SUSY breaking scale only. However, the "naturalness" as one of the MSSM principles does not seem to be the obligatory requirement from the QFT point of view. So establishing of the genuine SUSY scales hierarchy is a problem which can be unambiguously solved beyond the MSSM.

The arbitrariness in the choice of the scale hierarchy can be sufficiently diminished when the gauge coupling unification is considered as the most fundamental theoretical basis. With this consideration as a starting point, we have found that the one-loop RG study, involving SUSY $SU(5)$ degrees of freedom placed near M_{GUT}, allows one to select some specific classes of the scale hierarchies. The proton stability is provided simultaneously.

It was shown that states near M_{GUT} should be taken into account as threshold corrections; they are crucially important for the selection of scales, giving sufficiently high unification point. Then the RG consideration at the one-loop level results in two classes of scenarios with an opposite arrangement of μ and $M_{1/2}$ scales. At the same time, the analysis does not fix the characteristic scalar scale M_0 due to a specific form of the RG equations which contain the squark and slepton scales as a ratio $M_{\tilde{q}}/M_{\tilde{l}}$ only.

For the first class of scenarios the hierarchy $|\mu| \gg M_{1/2}$ takes place. The second class is defined by the hierarchy $|\mu| \ll M_{1/2}$. Due to arbitrariness of M_0 it is possible to select some subscenarios with various M_0 arrangements. Among them there can be found some hierarchies corresponding to Split Symmetry and some ideologically close scenarios which do not reject fine-tuning and are motivated, on the one hand, by the anthropic principle and, on the other hand, multi-vacua string landscape arguments [1, 2, 3, 4, 5, 6] (see, however, comments in [7]).

In particular, the RG analysis results in the hierarchy

$$M_0 \sim M_{1/2} \gg |\mu| > M_{EW}, \tag{1.1}$$

whose spectrum contains two lightest neutralinos degenerated in mass (almost pure Higgsino) and one of charginos as the states that are the nearest to the electroweak scale. In this Split Higgsino scenario both M_0 and $M_{1/2}$ are shifted to scales $\sim (10^7 - 10^{10})$ TeV.

In this paper, we consider some features and manifestations of the last scenario only (a preliminary version of this work was presented in [8], see also [9]).

As it will be shown, direct observation of neutralino (Higgsino) in $\chi - N$ scattering is impossible nowadays due to a very small interaction cross section. As to collider experiments, the signature of neutralino and chargino production and decays at the LHC crucially depends on the mass splitting values for these degenerate states [9, 10, 11, 12, 13]. On the one hand,

observation of these hardly detectable effects means that it is possible to get important information on the high superstate structure, in particular, $\tilde{t}_{1,2}$ and their mixing, from one-loop calculations of the mass splitting [14, 15, 16]. On the other hand, if only these low-lying SUSY degrees of freedom are detected in experiments near a TeV scale, the conventional MSSM spectrum should necessarily be splitted in some manner to produce a high scale for other superstates. The value predicted for the diffuse gamma flux from the Galactic halo can be measured by GLAST or ACT in the near future but it is not peculiar to this scenario. Signals from direct photons do not contain any specific effects too [9].

Thus, the Split Higgsino scenario is an example of SUSY models, in which the lightest degrees of freedom manifest themselves in some subtle effects as specific decay channels, correlating with the value of diffuse (or direct) gamma flux. Note, even if collider experiments will demonstrate the absence of the lowest neutralino signals (due to a high degeneracy of states, for example, it will certainly testify to some fine-tuning in the SUSY states spectrum), the SUSY, as a theoretical principle, cannot be rejected. At low $O\,(1\,\mathrm{TeV})$ energies the SUSY, in a sense, is barely hidden, so it exists at a high scale.

The structure of the paper is as follows. In Section 2, we discuss RG analysis of the SUSY $SU(5)$ in detail, indicating the most interesting scenarios. In Section 3, the Lagrangian of the Split Higgsino model and its analysis are presented. There is also an estimation of the lowest Higgsino mass from the relic abundance data. We discuss expected experimental manifestations of the scenario in Section 4 and some conclusions are in Section 5.

II. RENORMGROUP ANALYSIS

We consider one-loop RG equations for running couplings and start from their values at the M_Z scale

$$\begin{aligned}\alpha^{-1}(M_Z) = 127.922 \pm 0.027, \qquad \alpha_s(M_Z) = 0.1200 \pm 0.0028,\\ \sin^2\theta_W(M_Z) \;=\; 0.23113 \pm 0.00015.\end{aligned} \tag{2.1}$$

In renormgroup equations the following values are used as initial:

$$\begin{aligned}\alpha_1^{-1}(M_Z) = \frac{3}{5}\alpha^{-1}(M_Z)\cos^2\theta_W(M_Z) &= 59.0132 \mp (0.0384)_{\sin^2\theta_W} \pm (0.0124)_{\alpha},\\ \alpha_2^{-1}(M_Z) = \alpha^{-1}(M_Z)\sin^2\theta_W(M_Z) &= 29.5666 \pm (0.0192)_{\sin^2\theta_W} \pm 0.0062)_{\alpha},\\ \alpha_3^{-1}(M_Z) = \alpha_s^{-1}(M_Z) &= 8.3333 \pm 0.1944.\end{aligned} \tag{2.2}$$

At the one-loop level the equations for running couplings are well-known

$$\alpha_i^{-1}(Q_2) = \alpha_i^{-1}(Q_1) + \frac{b_i}{2\pi}\ln\frac{Q_2}{Q_1}, \qquad b_i = \sum_j b_{ij}. \tag{2.3}$$

In the sum all states with masses $M_j < Q_2/2$ at $Q_2 > Q_1$ are taken into account.

Namely, we include in the RG analysis the following degrees of freedom: singlet quarks and their superpartners $(D_L,\, \tilde{D}_L)$, $(D_R,\, \tilde{D}_R)$ contained in super-Higgs quintets of SUSY $SU(5)$; chiral superfields $(\Phi_L,\, \tilde{\Phi}_L)$ and $(\Psi_L,\, \tilde{\Psi}_L)$ in adjoint representations of $SU(2)$ and $SU(3)$, respectively, which survive from super Higgs 24-plet. In the minimal SUSY $SU(5)$ masses of the states $M_5 = (M_D,\, M_{\tilde{D}})$, $M_{24} = (M_\Psi,\, M_{\tilde{\Psi}},\, M_\Phi,\, M_{\tilde{\Phi}})$ are generated by an

interaction with Higgs condensate at the GUT scale, but the interaction couplings are not fixed. For the analysis we assume masses M_5, M_{24} to be slightly lower than M_{GUT}. Note that heavy states near M_{GUT} are of especial importance for the RG equations. The necessity of taking into account of such heavy states in the RG analysis as so-called threshold corrections is well-known [17, 18, 19, 20, 21, 22].

For one-loop running couplings at the scale $q^2 = (2M_{GUT})^2$ we have

$$
\begin{aligned}
\alpha_1^{-1}(2M_{GUT}) &= \alpha_1^{-1}(M_Z) - \frac{103}{60\pi}\ln 2 + \frac{1}{2\pi}\left(-7\ln M_{GUT} + \frac{4}{15}\ln M_D + \frac{2}{15}\ln M_{\tilde{D}}\right. \\
&\left. + \frac{11}{10}\ln M_{\tilde{q}} + \frac{9}{10}\ln M_{\tilde{l}} + \frac{2}{5}\ln\mu + \frac{1}{10}\ln M_H + \frac{17}{30}\ln M_t + \frac{53}{15}\ln M_Z\right), \\
\alpha_2^{-1}(2M_{GUT}) &= \alpha_2^{-1}(M_Z) - \frac{7}{4\pi}\ln 2 + \frac{1}{2\pi}\left(-3\ln M_{GUT} + \frac{4}{3}\ln M_{\tilde{\Phi}} + \frac{2}{3}\ln M_{\Phi}\right. \\
&\left. + \frac{3}{2}\ln M_{\tilde{q}} + \frac{1}{2}\ln M_{\tilde{l}} + \frac{4}{3}\ln M_{\tilde{W}} + \frac{2}{3}\ln\mu + \frac{1}{6}\ln M_H + \frac{1}{2}\ln M_t - \frac{11}{3}\ln M_Z\right), \\
\alpha_3^{-1}(2M_{GUT}) &= \alpha_3^{-1}(M_Z) + \frac{23}{6\pi}\ln 2 + \frac{1}{2\pi}\left(-\ln M_{GUT} + 2\ln M_{\tilde{\Psi}} + \ln M_{\Psi}\right. \\
&\left. + \frac{2}{3}\ln M_D + \frac{1}{3}\ln M_{\tilde{D}} + 2\ln M_{\tilde{q}} + 2\ln M_{\tilde{g}} + \frac{2}{3}\ln M_t - \frac{23}{3}\ln M_Z\right).
\end{aligned}
\tag{2.4}
$$

Here $M_0 = (M_{\tilde{q}},\, M_{\tilde{l}})$ are masses of scalar quarks and leptons averaged over chiralities and generations; M_t is t-quark mass; other parameters were introduced above. In (2.4) it is supposed that the lightest Higgs boson mass m_h is near to M_{EW} and other Higgs bosons H, A, $H^{\pm}$ are placed at some high M_H scale. For extra heavy states the only condition is $M_{24},\ M_5 < M_{GUT}$ and we suppose that this inequality is fulfilled with accuracy within 1 - 2 orders of magnitude. As to SUSY degrees of freedom M_0, $M_{1/2}$, μ, M_H, equations (2.4) do not depend on any specific arrangement of these scales. So when M_{GUT} is the highest scale in the system, there is no necessity to establish an initial scale hierarchy. The only demand is that the RG equations should lead to coupling unification at sufficiently high M_{GUT} scale for the proton stability. Then the set of possible hierarchies of energy scales arises as the final result of the study. Note also that if masses of singlet superstates and residual Higgs superfields are equal to M_{GUT}, equations (2.4) return to the standard form automatically.

The above considerations together with experimental restrictions on the SUSY mass spectrum and general expectation of the lightest Higgs boson scale (it is not very far from the EW scale) are sufficient for the RG analysis.

As the first step, all couplings were recalculated at the $2M_Z$ scale, all the SM states contribute to running of couplings despite $W^{\pm}$, Z^0, Higgs bosons, and t-quark. At the same time, terms with $\ln 2$ occur which are quantitatively important for calculations. Between the $(2M_Z,\ 2M_t)$ scales the following states emerge: $W^{\pm}$, Z^0 and one Higgs doublet containing light h-boson and longitudinal degrees of freedom of $W^{\pm}$, Z^0. At these stages, $Z\bar{q}q$ vertex was used for calculations of $\alpha_2^{-1}(2M_t)$, starting from $\alpha_2^{-1}(2M_Z)$ value. Above $2M_t$ calculations were carried out in a standard manner.

Now, equating couplings at M_{GUT}, from (2.4) we get the following expressions:

$$M_{GUT} = Ak_1 M_Z \left(\frac{M_Z}{M'_{1/2}}\right)^{2/9}, \qquad \mu = Bk_2 M_Z \left(\frac{M_Z}{M'_{1/2}}\right)^{1/3}, \tag{2.5}$$

where

$$\begin{aligned} k_1 &= K_{\tilde{q}\tilde{l}}^{-1/12} K_{GUT1}^{1/3} \equiv \left(\frac{M_{\tilde{l}}}{M_{\tilde{q}}}\right)^{1/12} \left(\frac{M_{GUT}}{M'_{GUT}}\right)^{1/3}, \\ k_2 &= K_{Ht}^{-1/4} K_{\tilde{q}\tilde{l}}^{1/4} K_{\tilde{g}\tilde{W}}^{-5/2} K_{GUT2}^{-1} \equiv \left(\frac{M_{top}}{M_H}\right)^{1/4} \left(\frac{M_{\tilde{q}}}{M_{\tilde{l}}}\right)^{1/4} \left(\frac{M_{\tilde{g}}}{M_{\tilde{W}}}\right)^{5/2} \left(\frac{M''_{GUT}}{M_{GUT}}\right), \end{aligned}$$

$$M'_{1/2} \equiv (M_{\tilde{W}} M_{\tilde{g}})^{1/2}, \qquad M'_{GUT} \equiv (M_{\tilde{\Psi}} M_{\tilde{\Phi}})^{1/3} (M_\Psi M_\Phi)^{1/6} \leq M_{GUT},$$

$$M''_{GUT} \equiv \frac{(M_{\tilde{\Psi}}^2 M_\Psi)^{7/6} (M_D^2 M_{\tilde{D}})^{1/2}}{(M_{\tilde{\Phi}}^2 M_\Phi)^{4/3}} \leq M_{GUT},$$

$$A = \exp\left(\frac{\pi}{18}(5\alpha_1^{-1}(M_Z) - 3\alpha_2^{-1}(M_Z) - 2\alpha_3^{-1}(M_Z)) - \frac{11}{18}\ln 2\right) = (1.57 \times^{1.09}_{0.92}) \cdot 10^{14},$$

$$B = \exp\left(\frac{\pi}{3}(5\alpha_1^{-1}(M_Z) - 12\alpha_2^{-1}(M_Z) + 7\alpha_3^{-1}(M_Z)) + \frac{157}{12}\ln 2\right) = (2.0 \times^{0.15}_{6.56}) \cdot 10^{3}.$$

Here all dimensionless parameters K with various indices are defined as quantities having values larger than unity (see also [23]). Note that K_{GUT1}, K_{GUT2} are not under theoretical control either in the MSSM or in the SUSY $SU(5)$. So we assume that $1 \leq K_{GUT1} \simeq K_{GUT2} \leq 10$. For the lightest Higgs boson there is an experimental restriction [24]: $M_h > 114.4$ GeV, as to other (heavy) Higgs bosons the following interval $2 \leq K_{Ht} \leq 10$ is supposed for the numerical analysis. Values of $K_{\tilde{q}\tilde{l}}$, $K_{\tilde{g}\tilde{W}}$ can be determined from the renormgroup evolution from M_{GUT} to M_0, $M_{1/2}$. Here we suppose that $1.5 \leq K_{\tilde{q}\tilde{l}} \simeq K_{\tilde{g}\tilde{W}} \leq 2.5$. Now all dimensionless parameters are fixed in some intervals and we analyze $M'_{1/2}$ and μ as functions of M_{GUT}:

$$M'_{1/2}(M_{GUT}) = (Ak_1)^{9/2} M_Z^{11/2} \times M_{GUT}^{-9/2}, \qquad \mu(M_{GUT}) = \frac{Bk_2}{(Ak_1)^{3/2} M_Z^{1/2}} \times M_{GUT}^{3/2}. \tag{2.6}$$

As it is seen, the initial system of equations for three running couplings can be rewritten as a system of two equations for the effective gaugino $M'_{1/2}$ and μ scales, depending on M_{GUT}. It is very essential that all other characteristic scales arise in the equations as dimensionless ratios only. (This method of RG analysis was used in [23] for investigation of SUSY $SU(5)$ and E_6 energy scale hierarchies; see also [20, 22].)

As an important feature, we have to note that the renormgroup study remains a common scalar scale M_0 as an arbitrary one: the scale M_0 turns into (2.6) through the ratio $M_{\tilde{q}}/M_{\tilde{l}}$ only. For numerical predictions the ratio value was estimated as $O(1)$. Certainly, the splitting of the $M_{\tilde{q}}$ and $M_{\tilde{l}}$ scales will affect the hierarchies of other scales. However, to change these hierarchies crucially, the ratio $M_{\tilde{q}}/M_{\tilde{l}}$ must be $\sim O(100)$ or larger, and here we do not consider this possibility. Also, we suppose that radiative corrections to superscalar

masses do not change the ratio substantially (numerically, these corrections can be as large as $(1-5)\,\%$, see [14]). Conclude, the scale M_0 should be fixed by some extra arguments independently.

Contributions of heavy states M_{24}, M_5 do not affect the RG hierarchy of SUSY scales radically because their scales are combined into a ratio too. Nevertheless, the ratio value is important to fix the M_{GUT} scale: the ratio M_{24}/M_5 depends on M_Z logarithmically, so numerical coefficients of the ratio can change the M_{GUT} value.

For the analysis we used the known restrictions for the proton lifetime ($\tau_p \geq 10^{32}$ yr at $M_{GUT} \geq 10^{15}$ GeV) and for M_{SUSY} that is $\sim M'_{1/2} > 100$ GeV when $M_{GUT} < 3 \cdot 10^{16}$ GeV). We hope also that loop corrections to all masses in the model do not change results of the RG analysis drastically, it is supposed that for the scenario they contribute no more than $\sim (10-15)\,\%$ [14, 15].

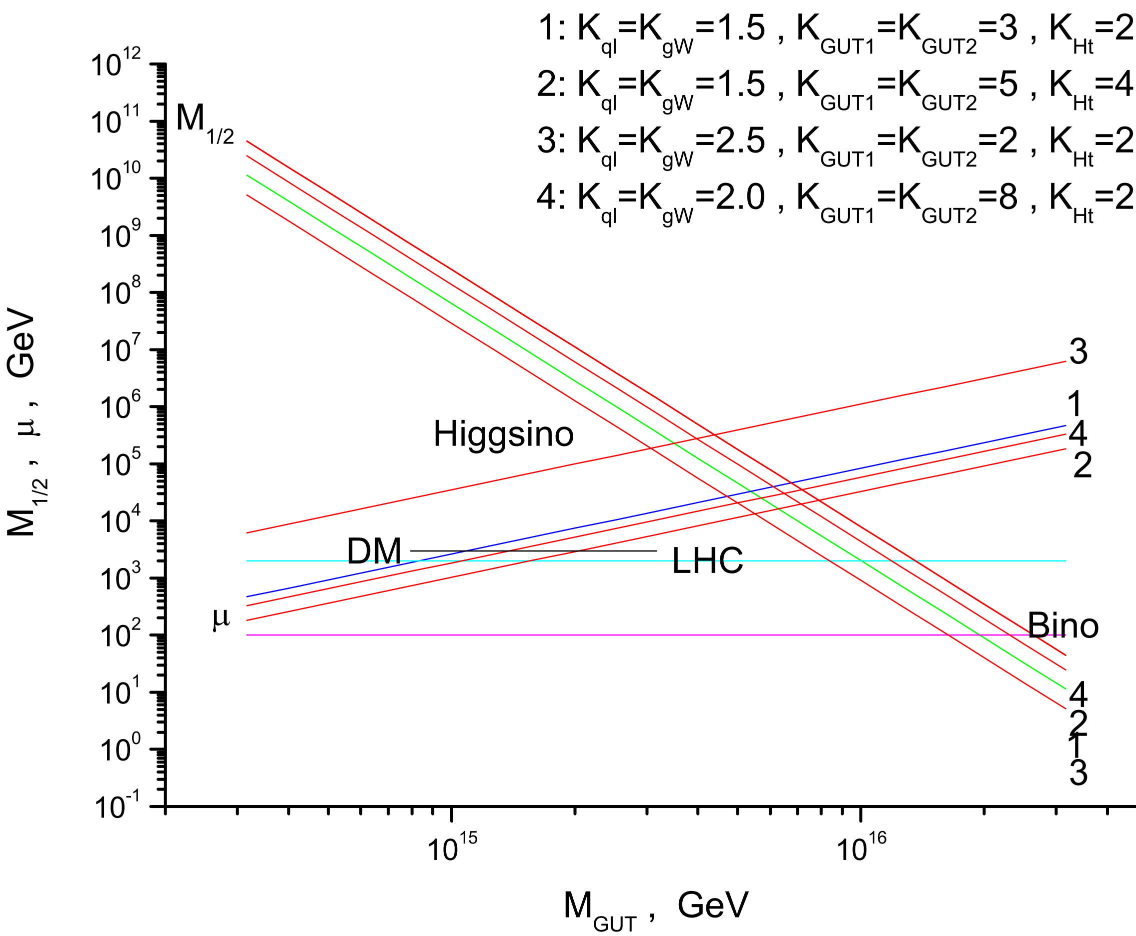

FIG. 1: SUSY $SU(5)$ hierarchies of scales permitted by the one-loop RG analysis.

Numerical results following from (2.6) are shown in Fig. 1. It is clearly seen that the proposed method of the one-loop RG analysis results in the selection of two proper sets of SUSY scales only (further we will omit differences between $M'_{1/2}$ and $M_{1/2}$). For this

conclusion we assume that the characteristic μ scale is in the $O(1\,\text{TeV})$ region, providing the neutralino mass value that is sufficient for explanation of the DM properties.

The first class of scenarios is defined by the hierarchy

$$|\mu| \gg M_{1/2} \gtrsim M_{EW}.$$

As it was noted, M_0 value does not affect this scale splitting dictated by the one-loop RG evolution, and can be placed at an arbitrary but physically reasonable scale. So the class could be divided into some subscenarios with hierarchies

$$\begin{array}{ll} (a) & M_0 \gg |\mu| \gg M_{1/2} \gtrsim M_{EW}, \\ (b) & M_0 \sim |\mu| \gg M_{1/2} \gtrsim M_{EW}, \\ (c) & |\mu| \gg M_0 \gg M_{1/2} \gtrsim M_{EW}, \\ (d) & |\mu| \gg M_0 \sim M_{1/2} \gtrsim M_{EW}. \end{array}$$

The subscenarios (a), (b) and (c) are close to the known Split SUSY (Gaugino) models [1, 2, 3], but the variant (d), keeping most part of the SUSY degrees of freedom (except Higgsino) near the EW scale, is similar to the MSSM spectrum with "naturalness". For these variants we get $M_{GUT} = (1-5)\cdot 10^{16}\,\text{GeV}$ and gaugino masses can be as small as $(0.1-1.0)\,\text{TeV}$.

The second set of scenarios is generated by the hierarchy

$$M_{1/2} \gg |\mu| > M_{EW}.$$

In this set we have the following subscenarios:

$$\begin{array}{ll} (e) & M_0 \gtrsim M_{1/2} \gg |\mu| > M_{EW}, \\ (f) & M_{1/2} \gg M_0 \sim |\mu| > M_{EW}, \\ (g) & M_{1/2} \gg M_0 \gg |\mu| > M_{EW}, \\ (h) & M_{1/2} \gg |\mu| > M_0 \gtrsim M_{EW}. \end{array}$$

Except the last variant (h) with too low M_0 scale as contradicting known experimental data, the other scenarios of this class seem reasonable. All of them introduce Higgsino as the DM carrier. Note that the hierarchy (f) is close to the MSSM spectrum again, despite gaugino states at a high scale. Scenarios (e) and (g) shift M_0 and $M_{1/2}$ scales into a multi-TeV region, splitting the spectrum. In these cases, the μ scale is the nearest to the EW scale and should be near $1\,\text{TeV}$, as it follows from the RG analysis. As to the unification scale, we have the value $M_{GUT} = (1-2)\cdot 10^{15}\,\text{GeV}$ which makes the proton stable.

Obviously, Split SUSY models with high M_0 and $M_{1/2}$ scales lead to the damping of heavy states (squarks, sleptons) contributions near the EW scale. Another important consequence of this type of scenarios is (nearly) degeneration in mass of the lowest neutralino and chargino states [9, 11, 13, 16, 25, 26] (experimental searches of this degenerated states were carried out at LEP energies [27] without any evident signals).

Further, we will consider the Split Higgsino scenario with hierarchy

$$M_0 \gtrsim M_{1/2} \gg |\mu| > M_{EW}.$$

Taking M_{GUT} value as $\gtrsim 10^{15}$ GeV, for $\mu = 1.0$ TeV the SUSY breaking scale is $M_{SUSY} \sim M_{1/2} \sim (0.1-2.5)\cdot 10^8$ GeV; when $\mu = 1.4$ TeV we get $M_{SUSY} \sim (0.5-2.8)\cdot 10^8$ GeV. For

these cases $M_{GUT} \sim (1.0 - 1.7) \cdot 10^{15}$ GeV. The used values of μ, as it will be seen further, agree with modern data on relic DM abundance. Intervals of M_{SUSY} values follow mainly from uncertainties in the parameters K_{GUT1} and K_{GUT2}. Most evidently, the scenario is selected when K_{GUT1}, $K_{GUT2} \sim 5 - 8$; it means that the effect of threshold corrections is essentially important for the discovery of hierarchy. Namely, if masses M_{24}, M_5 are equal to M_{GUT}, it is questionable to select several possible scenarios that are compatible with the DM data.

These one-loop results should be refined with taking into account of two-loop β-functions and loop corrections to masses. By now we expect that two-loop RG analysis does not change the above hierarchies radically as well as mass corrections. Certainly, various numerical coefficients will change, arrangements of the scales will move somehow, but the relative spacing between μ and $M_{1/2}$ scales will not change, as we hope. Nevertheless, the M_0 scale can be splitted by the RG at the two-loop level, so positions of the $M_{\tilde{q}}$ and $M_{\tilde{l}}$ scales can be determined independently. More carefully this question will be analyzed in a forthcoming paper. Now we will consider the Lagrangian of the Split Higgsino scenario, its structure, and features.

III. THE SPLIT HIGGSINO SCENARIO

A. The model Lagrangian and its features

When the group of symmetry is fixed, the Lagrangian as a local gauge group invariant can be written in a standard manner. Nevertheless, its specific form depends on the chosen field representation. In this paper, we use the formalism of Majorana spinors and define all physical fields as having positive masses only.

More precisely, in the scenario considered the neutralino mixing parameter is proportional to the ratio M_Z/M_{SUSY}, so it is negligibly small due to a high scale of SUSY breaking. However, the mixing can be important when the model restrictions are analyzed in the framework of a specific mass spectrum with a small splitting of the lightest neutralino masses.

As to neutralino masses, i.e., the scale of μ parameter, diagonalization of the neutralino mass matrix by an orthogonal matrix usually leads to emerging of neutralino state with negative mass. This should be taken into account in calculations by the corresponding definition of the propagator (if negative mass neutralino is in the intermediate state) or in the neutralino polarization matrix (if the neutralino is in the initial or in the final state). To evade this inconvenience, we redefine the neutralino field with the negative mass in the following way: $\chi \to i\gamma_5\chi$. This operation provides positive neutralino mass keeping standard calculation rules simultaneously. Moreover, it does not change Majorana type of the field. It also has been shown that this procedure is equivalent to the diagonalization by the unitary matrix instead of the orthogonal one, for details see [28].

Hence, in the scenario two lowest neutralino states are Majorana Higgsino-like ones. The set of scales leads to the strong splitting in the neutralino and chargino spectra, so masses of these lightest neutralinos $\chi^0_{1,2}$ and the light chargino $\chi^\pm_1$ emerge near the μ scale. Light neutralino states are built from the initial fields $h_{1,2}$ in the limit of pure Higgsino when

$m_Z/\mu \to 0$ and $m_Z/M_{SUSY} \to 0$; here $M_{SUSY} \sim M_1 \sim M_2$. Masses of the lightest states are

$$\begin{aligned} M_{\chi_1^0} &\simeq \mu - \frac{M_Z^2(1+\sin 2\beta)}{2M_1M_2}(M_1\cos^2\theta_W + M_2\sin^2\theta_W), \\ M_{\chi_2^0} &\simeq \mu + \frac{M_Z^2(1-\sin 2\beta)}{2M_1M_2}(M_1\cos^2\theta_W + M_2\sin^2\theta_W), \\ M_{\chi_1^\pm} &\simeq \mu - \mu\frac{M_W^2}{M_2^2} - M_W\frac{M_W}{M_2}\sin 2\beta. \end{aligned} \tag{3.1}$$

It is seen that the spectrum of the lowest states, $\chi^0_{1,2}$ and $\chi^\pm_1$, is nearly degenerated. For the Higgsino DM this fact is known (see, for example, [16, 25, 26, 29]). Two other neutralino states, $\chi^0_{3,4}$, and heavy chargino $\chi^\pm_2$ are placed far from the lightest ones, near the high scale M_{SUSY}.

The initial Lagrangian of $Z - h_{1,2}$ interactions, including the μ-term, is the following (for more details see [28])

$$L = \frac{1}{2}g_Z Z_\mu(\bar{h}_{1L}\gamma^\mu h_{1L} + \bar{h}_{2R}\gamma^\mu h_{2R}) - \mu(\bar{h}_{1R}h_{2L} + \bar{h}_{1L}h_{2R}). \tag{3.2}$$

Taking into account that $\bar{h}_{aL}\gamma^\mu h_{aL} = -\bar{h}_{aR}\gamma^\mu h_{aR}$, $\bar{h}_{1R}h_{2L} = \bar{h}_{2R}h_{1L}$, from (3.2) in the limit of pure neutral Higgsino it follows:

$$L = -\frac{1}{2}g_Z Z_\mu \bar{h}_D\gamma^\mu h_D - \mu\bar{h}_D h_D, \tag{3.3}$$

where $h_D = h_{1R} + h_{2L}$ is the Dirac neutral field and $g_Z = g_2/\cos\theta_W$. When the field h_D is expressed through Majorana fields χ_1 and χ_2 as

$$h_D \equiv h_{1R} + h_{2L} = (\chi_1 - i\chi_2)/\sqrt{2}, \tag{3.4}$$

for the transition $(h_1, h_2) \to (\chi_1, \chi_2)$ we get

$$h_{1,2} = \frac{1}{\sqrt{2}}(\chi_1 \mp i\gamma_5\chi_2); \qquad \chi_1 = \frac{1}{\sqrt{2}}(h_1 + h_2), \quad \chi_2 = \frac{i}{\sqrt{2}}(h_1 - h_2). \tag{3.5}$$

All processes near the EW scale are described by the SM Lagrangian together with extra Lagrangian of the Higgsino interactions with photons and vector bosons:

$$\begin{aligned} \Delta L &\simeq -\left(eA_\mu + \frac{g_2}{2\cos\theta}\cos 2\theta Z_\mu\right)\bar{\chi}_c\gamma^\mu\chi_c + \frac{ig_2}{2\cos\theta}Z_\mu\bar{\chi}_1^0\gamma^\mu\chi_2^0 + \\ &- \frac{g_2}{2}W_\mu^+(i\bar{\chi}_1^0 + \bar{\chi}_2^0)\gamma^\mu\chi_c + \frac{g_2}{2}W_\mu^-\bar{\chi}_c\gamma^\mu(i\chi_1^0 - \chi_2^0), \end{aligned} \tag{3.6}$$

where χ_c denotes the lowest chargino state, $\chi_1^\pm$. Remember that $\chi^0_{1,2}$ states are the Majorana spinors and chargino χ_c is the Dirac spinor.

In the above Lagrangian the vertices are considered in the limit of zero mixing, because contributions to the vertices induced by a mixing are of an order of M_Z/M_{SUSY}. So corrections induced by mixing are negligibly small and can be omitted. However, the same small mixing contributions to the particle mass spectrum should be involved into analysis. The reason is that the decay widths depend on the mass splitting crucially.

B. Split Higgsino as the DM carrier

Supposing that the lightest Higgsino-like neutralino is a carrier of the DM in the Universe, we evaluate its mass from the DM relic abundance.

In accordance with the known method for the relic abundance calculation (see, for example, [30, 31, 32, 33] and [34] with references therein) before freeze-out neutralinos are in the thermodynamical equilibrium with other components of the cosmological plasma. Relic is formed by the irreversible annihilation process – from the moment, when the freeze-out is reached, up to the present day when temperature is approximately equal to absolute zero (this approximation is sufficient for the case). With the standard estimation of $x_f = M_\chi/T_f \approx 20-25$ the value of T_f can be well above $T_{EW} \sim 100$ GeV only if $m_\chi > 2$ TeV. Now, if the lowest Higgsino masses were well above T_{EW}, the irreversible annihilation process could start before electro-weak phase transition (it is considered as the first order phase transition) in the high-symmetric phase of the cosmological plasma. Then the plasma does not contain any Higgs condensate, and all standard particles, except Higgsino, are massless (more exactly, their masses $\ll T$).

In the ordinary low-symmetric case, the neutralino annihilation cross section is calculated with the Lagrangian (3.6). In relic calculations all possible coannihilation channels were taken into account (there is no coannihilation with squarks and/or sleptons), namely

$$\begin{aligned} \chi_\alpha\bar{\chi}_\beta &\to ZZ, \quad W^+W^- \\ \chi_c\bar{\chi}_c &\to ZZ, \quad W^+W^-, \quad f\bar{f}, \quad \gamma\gamma, \quad Zh \\ \chi_\alpha\bar{\chi}_c &\to ZW, \quad l\nu_l, \quad q_i\bar{q}_j, \quad \gamma W, \quad Wh, \end{aligned} \tag{3.7}$$

where α, $\beta = 1, 2$ denote the lowest neutralino states.

In the scenario the effective neutralino annihilation cross section is:

$$\begin{aligned} < (\sigma v)_{ann} >= \frac{g_2^4}{128\,\pi M_\chi^2} \cdot \Big\{ 27 + 4(3+5t_W^4)(c_W^4+s_W^4) - kc_W^2 + \frac{k^2}{4}(c_W^4+s_W^4) + \\ \frac{1}{2\,c_W^4}\left[1+\frac{1}{8}(c_W^4+s_W^4)+(c_W^2-s_W^2)^4\right] + \frac{1}{2\,c_W^2}\left[s_W^4\left(10-\frac{1}{k}\right)+2kc_W^2\right]\Big\}, \end{aligned} \tag{3.8}$$

where $t_W = \tan\Theta_W$, $s_W = \sin\Theta_W$, $c_W = \cos\Theta_W$ and $k = M_Z^2/M_W^2$. To compare the calculated value of Ωh^2 with an experimental corridor of the relic data [35], we use known values of the above parameters and extract the following LSP (Higgsino) mass: $M_\chi = 1.0 - 1.4$ TeV for $x_f = 25$ and $M_\chi = 1.4 - 1.6$ TeV for $x_f = 20$. These values do not spoil the gauge coupling convergence and are in agreement with the results from [2, 3, 9, 29]. Thus, in the model where two lightest neutralinos and one chargino are the closest to the EW scale having masses $O(1$ TeV$)$. Further, we will use $M_\chi = 1.4$ TeV for all numerical estimations as an average value.

To answer whether the neutralino annihilation process can start in the high-symmetric phase, we calculate the annihilation cross section with the Lagrangian which contains physical states presented by chiral fermions and gauge fields $B, W_a\,(a = 1, 2, 3)$. Due to the absence of the Higgs condensate neutralino and chargino degrees of freedom join into the fundamental $SU(2)$ representation, i.e., Dirac field χ_D. All states of this field are dynamically equivalent and correspond to quantum numbers of the restored (unbroken) $SU(2)$ symmetry.

In t- and s-channels all cross sections of Higgsino annihilation into gauge bosons and massless fermions were calculated analogously to the QCD calculation technology. The only difference is that it is necessary to consider all channels with initial and final states which have an arbitrary color in two dimensions, corresponding to the restored $SU(2)$ symmetry. Calculating the total neutralino annihilation cross section, from the known corridor of the relic abundance values we get the lowest Higgsino mass ~ 1 TeV again. It contradicts the initial supposition that $M_\chi > 2$ TeV to provide freeze-out temperature higher than the EW phase transition temperature. So in the framework of orthodox notions (mechanisms of extra entropy production or superheavy states decays, etc. are not considered) this scenario does not allow the DM to be created in the high symmetric phase.

IV. SUSY SCALES AND EXPERIMENTAL POSSIBILITIES

A. $\chi - N$ scattering and collider signals

It is important to understand how an experimental study of the Split Higgsino scenario can be realized. Here we discuss some possibilities that can be given by neutralino-nucleon scattering processes, collider experiments with SUSY particles creation and the data on photon spectrum from neutralino annihilation. The last one will be considered in the next subsection.

An experimental observation of the scenario manifestations depends on neutralino mass splitting parameters $\Delta M_{\chi^0} = M_{\chi^0_2} - M_{\chi^0_1}$ and $\Delta M_{\chi_c} = M_{\chi_c} - M_{\chi^0_2}$ crucially. These splittings are determined by the sum of tree splittings and radiative corrections to masses. Depending on the M_0 spacing and structure of high energy states, loop corrections can be comparable with tree values of ΔM_χ (ΔM_{χ^0} or ΔM_{χ_c}) or even exceed them [12, 14, 15, 16, 26]. As it is known [16], the hierarchy of $\tilde{t}_1$ and $\tilde{t}_2$ states and their mixing angle Θ_t drive the value of the mass difference when squarks dominate in loops $\Delta M_{\chi_c} \sim \Delta M_{\chi^0} \sim m_t^3 \sin(2\Theta_t) \cdot \ln(m^2_{\tilde{t}_1}/m^2_{\tilde{t}_2})$. Due to these (large) corrections the mass splittings can be increased up to $\sim 10\,\mathrm{GeV}$ [16, 26]. Then let us consider two possible variants.

Firstly, let there be large mass splittings $\Delta M_\chi \sim (1-10)$ GeV or even larger. When this is the case, the lowest Higgsino and chargino states can be detected at the LHC, in particular, due to specific decay channels of χ^0_2 and χ_c – the corresponding analysis was considered in some detail in [9, 10, 11, 12], so we do not repeat it here. In the Split Higgsino hierarchy $M_0 \gtrsim M_{1/2} \gg \mu$, squarks (sleptons) slip out of the LHC experiment (together with the high energy gaugino), keeping specific chargino (neutralino) decays as the observable only.

If, however, $M_{1/2} \gg M_0$, there are two additional possibilities. Namely, if $M_{1/2} \gg M_0 \sim \mu$, i.e., squarks (sleptons) have masses $\sim (1-2)$ TeV, an occasion arises to observe their signals at the LHC. (If $m_{\tilde{q}}$ and/or $m_{\tilde{l}}$ are sufficiently close to the lowest neutralino mass, some coannihilation contribution to the effective neutralino annihilation cross section is produced.) When $M_{1/2} \gg M_0 \gg \mu$ there are no observable effects of squarks (sleptons) at the LHC scale.

Both of these last subscenarios are very peculiar due to a large splitting between $M_{1/2}$ and M_0 – it can produce relatively long-lived superscalars at TeV (or higher) scale. In this case, specific manifestations of these states both at colliders (long-lived squarks and /or sleptons, changes in their decay modes hierarchy etc.), and in neutralino-nucleon scattering (large contribution to SI interaction) should be. In this paper, however, we concentrate only on the scenario with $M_{1/2} \sim M_0$ where superscalars are very heavy.

Neutralino-nucleon interaction in the scenario behaves as a threshold process due to the formalism accepted – the corresponding term in the Lagrangian is nondiagonal in neutralino fields: $i(g_2/2\cos\theta)Z_\mu\bar{\chi}_1^0\gamma^\mu\chi_2^0$. In the case of pure neutralino states, zero order contributions to $\chi - N$ interaction correspond to the spin-independent (SI) inelastic process. This conclusion results from the interaction Lagrangian – nondiagonal Higgsino current $\chi_1^0\gamma_\mu\chi_2^0$ interacts with Z_μ as a vector, rather than an axial vector, it is a consequence of the real 4-dimensional Majorana formalism used (see [28]).

At the tree level the zero order SI cross section for $\chi_1^0 - N$ reaction takes the following threshold form

$$\sigma_{\chi^0 N}^{SI} = \frac{g^4 M_N^2}{64\pi\cos^4\theta_W M_Z^4}\left(\frac{E_N - \Delta M_{\chi^0}}{E_N}\right)^{1/2}. \tag{4.1}$$

In the non-relativistic case $E_N = W_k(m_N/M_\chi)$, where W_k is an average kinetic energy of the neutralino in the Sun neighborhood, $W_k = M_\chi v_r^2/2$. For $M_{\chi^0} \sim 1$ TeV this energy $W_k \sim 1$ MeV. So for ΔM_{χ^0} as large as $(1-10)$ GeV the threshold value for the reaction energy is unattainable. Then the process is forbidden, and cosmic neutralinos cannot be detected in the direct terrestrial experiments.

The cross section for the neutralino-nucleon scattering with chargino production (recharge process) is similar to (4.1) and for large $\Delta M_{\chi_c} \approx 0.5\,\Delta M_{\chi^0}$ this channel is also closed.

Corrections induced by a nonzero mixing and/or loop diagrams cannot make these nondiagonal reactions visible because part of correction amplitudes is damped in the limit of pure Higgsino; contributions from squark exchanges are small due to large squark masses (see also [36, 37]). Furthermore, due to Majorana nature of neutralino, nonzero loop contributions are proportional to the small parameter $q^2/M_Z^2 \ll 1$. As concerns elastic (diagonal) channels, they contribute to the $\chi - N$ cross section via loops or due to a nonzero mixing, so their yield is small as well.

Returning to some RG arguments, it seems that when $M_0 \gtrsim M_{1/2}$ we can expect ΔM_χ somewhat lower than for the case $M_{1/2} \gg M_0$ when the splitting between $\tilde{t}_1$ and $\tilde{t}_2$ can be larger. Certainly, the relative splitting and mixing of these states are really unknown.

So let us consider the second case with $\Delta M_\chi < 1$ GeV and it can be as low as $\sim(100-300)$ MeV if mass splittings are mainly determined by tree contributions. As to collider signature, in this case only photon, neutrino pair or low energy e^-e^+, $\mu^-\mu^+$, $\pi^-\pi^+$ pairs can be created in the final states, but it is hard to select these events from the background (see also [9, 10, 11]). So in the case of low ΔM_χ, degenerated Higgsino and chargino are indeed invisible at the LHC.

The Higgsino-nucleon nondiagonal interaction takes place again in this case, contributing to the SI cross section. Comparing the model predictions for $\chi - N$ reaction with experimental restrictions on the SI cross section [38, 39] it is possible to estimate the M_{SUSY} value. From the inequality

$$\Delta M_{\chi^0} = (M_Z^2/(M_1 M_2)(M_1\cos^2(\theta_W) + M_2\sin^2(\theta_W) < W_k(M_N/M_\chi),$$

it follows that the process $\chi_1^0 N \to \chi_2^0 N'$ is closed when $M_{SUSY} \leq 8.3\cdot 10^9$ GeV and $M_{SUSY} \leq 1.2\cdot 10^{10}$ GeV for $M_{\chi_1^0} = 1.0$ TeV and 1.4 TeV, respectively. These estimations depend on $\tan\beta$ weakly and are in agreement with the ones given by the RG analysis. So we conclude that in this scenario the SI inelastic Higgsino-nucleon scattering cannot be observed experimentally today.

It seems that the inverse inelastic reaction $\chi_2^0 N \to \chi_1^0 N'$ is possible, but χ_2^0 states are unstable, so they decayed a long time ago. In other words, the only inequality $\tau_\chi \leq T_0$ takes place, where T_0 is the age of the Universe. An upper estimation for τ_χ follows from the width $\Gamma(\chi_2 \to \chi_1 \nu\bar{\nu})$ (when ΔM_{χ^0} is reasonably small we consider only the most "soft" channel) and we have

$$\Gamma_\chi = \frac{G_F^2}{60\pi^3}\Delta M_\chi^5. \tag{4.2}$$

Then the following restriction emerges

$$M_{SUSY} \leq M_Z^2 \left(\frac{G_F^2 T_0}{60\pi^3}\right)^{1/5}. \tag{4.3}$$

With the value $T_0 = 3.15 \cdot 10^{17}\, s$ we get $M_{SUSY} \leq 4.25 \cdot 10^9\,\mathrm{GeV}$. It is again in accordance with the RG results and slightly more stringent than the restrictions following from the threshold inequality $\Delta M_\chi \geq W_k(M_N/M_\chi)$.

Electroweak corrections to the splitting $\Delta M_{\chi^\pm}$ can be as small as $\sim 100\,\mathrm{MeV}$ due to loops with γ, Z and W [14]. When $\Delta M_{\chi^\pm} \sim 100\,\mathrm{MeV}$ (squark loop contributions are too small), recharge process $\chi_1^0 n \to \chi_1^\pm p$ accompanied by a track of $\chi^\pm$ seems as possible due to very energetic neutralinos, but their cross section is strongly damped and the reaction is entirely exotic. So the recharge process cannot be detected experimentally too.

Depending on mass splitting the chargino lifetime can be estimated in the following manner: from the channel $\chi^\pm \to \chi^0 e \bar{\nu}_e$ we get

$$\tau_{\chi^\pm} = (30\pi^3/G_F^2)\Delta M_{\chi_c}^{-5},$$

but in the intermediate interval of $\Delta M_{\chi^\pm} = (0.1 - 1.0)$ GeV there are also chargino decay channels with the final μ and π-meson. For these decays the corresponding formulae are more cumbersome, and we do not write them here. Gathering all contributions, we get approximately

$$\tau_{\chi^\pm} \sim (10^{-7} - 10^{-12})\; s.$$

Thus, for both the cases – large or small ΔM_χ – the subscenarios of this class do not produce practically any visible signal in various channels of neutralino-nucleon scattering at modern measuring tools.

If ΔM_χ values are sufficiently large, there is a chance to discover at the LHC some decay modes of the lowest neutralino and chargino states. Moreover, if some specific squark (slepton) effects occur at low TeV scale too, but gaugino manifestations are absent, it may correspond to the subscenario $M_{1/2} \gg M_0 \sim \mu$. The existence of specific neutralino-chargino decays together with the absence of other SUSY states at the TeV scale can be understood in the framework of the subscenarios $M_0 \gtrsim M_{1/2} \gg \mu$ or $M_{1/2} \gg M_0 \gg \mu$.

Absence in an experiment of various decay modes manifestations can indicate that the subscenarios with $M_0 \gtrsim M_{1/2} \gg \mu$ or $M_{1/2} \gg M_0 \gg \mu$ are realized, providing the lowest neutralino and chargino with a well degenerate spectrum that cannot be observed in experiment.

Note, for all scenarios with a large splitting between $M_{1/2}$ and M_0 a large contribution to the SI neutralino-nucleon cross section is possible due to the squark exchange, especially if the superscalar scale is closed to μ. Naturally, a study of collider and $\chi - N$ data correlations is necessary, making details of the state spectrum more precise. Data on neutralino annihilation photon spectrum are also needed to complete an analysis of capabilities of the scenarios.

B. Diffuse gamma spectrum from the Galactic halo

As it follows from above, in the Split Higgsino scenario obvious manifestations of SUSY can be in some latent form: direct interaction of neutralino with nuclei is too small and it is very questionable whether effects of degenerate neutralino and chargino can be detected at the LHC if $\Delta M_\chi < 10\,\mathrm{GeV}$. It seems that a chance to verify this scenario is to study the photon spectra from neutralino annihilation in the Galactic halo. The process can produce gamma quants in two ways: direct photon creation through loop diagrams or formation of a diffuse (continuous) gamma spectrum due to secondary photons created in radiative decays of mesons.

In this scenario the dominant mode of continuous gamma spectrum creation is Higgsino annihilation into WW and ZZ bosons followed by creation and radiative decays of light mesons, mainly through the channel $\pi^0 \to 2\gamma$. For the lowest Higgsino mass $M_\chi = 1.4$ TeV we calculate the cross section of Higgsino annihilation into WW and ZZ and get $(\sigma v)_{WW+ZZ} \approx 0.7 \cdot 10^{-26}\, cm^3 s^{-1}$. Further, the same spectrum

$$\frac{dN_\gamma}{dE_\gamma} \approx \frac{0.73}{m_\chi}\frac{e^{-7.76x}}{x^{1.5}},$$

where $x = E_\gamma / M_\chi$, is used for both (W and Z) channels approximately ([40, 41]).

Then the total diffuse photon flux from halo can be calculated as

$$\Phi^\gamma(E_0, E_m) \approx 9.3 \cdot 10^{-13}\, cm^{-2}\, s^{-1} \int_{E_0}^{E_m} dE_\gamma \frac{dN_\gamma}{dE_\gamma} \cdot \frac{< \sigma v >_{WW+ZZ}}{10^{-26}\, cm^3\, s^{-1}} \cdot \left(\frac{1\,\mathrm{TeV}}{m_\chi}\right) \cdot \bar{J}(\Delta\Omega) \cdot \Delta\Omega, \tag{4.4}$$

where E_0 is the threshold photon energy for an apparatus, E_m is the maximal registered photon energy, $\bar{J}(\Delta\Omega)$ is averaged over angle value of the integral $J(\Psi)$ which contains information on the DM distribution in halo [41, 42].

Fixing some value $\bar{J}(10^{-3}) \approx 1.2 \cdot 10^3$ that is typical of the Navarro-Frenk-White profile, where $\Delta\Omega = 10^{-3}\, sr$ is used (see [42, 43]), we evaluate the total continuous gamma flux that can be measured at space-based telescopes (EGRET or GLAST) or at ground based Atmospheric Cherenkov Telescopes (ACT) (HESS, in particular). Then from (4.5) for the total flux we get

$$\begin{aligned}
\Phi^\gamma_{EGRET} &\approx 0.17 \cdot 10^{-10}\, cm^{-2}\, s^{-1}, \quad E_0 = 1\,\mathrm{GeV},\; E_m = 20\,\mathrm{GeV}, \\
\Phi^\gamma_{GLAST} &\approx 0.19 \cdot 10^{-10}\, cm^{-2}\, s^{-1}, \quad E_0 = 1\,\mathrm{GeV},\; E_m = 300\,\mathrm{GeV}, \\
\Phi^\gamma_{HESS} &\approx 0.82 \cdot 10^{-12}\, cm^{-2}\, s^{-1}, \quad E_0 = 60\,\mathrm{GeV},\; E_m = 1\,\mathrm{TeV}.
\end{aligned} \tag{4.5}$$

As it is seen, the calculated values are beyond experimental possibilities of these telescopes – at present, only GLAST has some chance to measure the total continuous gamma flux, because it can detect a gamma flux as small as $\Phi^\gamma_{GLAST}(\exp) \approx 10^{-10}\, cm^{-2}\, s^{-1}$. In the near future, however, ACT like HESS, for example, will be able to fix the flux due to high sensitivity level [41] $\Phi^\gamma_{HESS}(\exp) \approx 10^{-14}\, cm^{-2}\, s^{-1}$. Note also that similar results were derived in [8] for direct photon signals.

A characteristic value of the flux is not characteristic feature of the scenario, nearly the same values arise in all schemes with highly degenerate Higgsino as the lowest state.

Nevertheless, from comparison with other model predictions (MSSM, mSUGRA, etc., see, for example [41, 42, 43, 44, 45, 46, 47]) we note that channel of neutralino annihilation into quarks increases the total flux up to one order of magnitude, so the flux could be well over the GLAST sensitivity threshold. Then the Split Higgsino scenario prediction for the diffuse gamma flux can be discriminated from predictions of models where there is a large contribution of quark and/or Higgs annihilation modes. Nevertheless, some conclusion on the Split Higgsino scenario realizability can be made only from the whole data analysis, using $\chi - N$ scattering, collider experiments, and photon spectrum data together.

V. CONCLUSIONS

We have pointed out that from the one-loop RG analysis of the SUSY $SU(5)$ theory there can be extracted a few sets of energy scales which are compatible with conventional ideas on the DM structure and manifestations. Threshold corrections, induced by heavy states near M_{GUT} – M_{24}, M_5, – are especially important for establishment of the hierarchies. Due to a specific form of the RG equations the scalar scale M_0 remains arbitrary, and it occurs the variety of scenarios divided in the two classes: $M_{1/2} \gg \mu$ or $M_{1/2} \ll \mu$. Note also that the refined RG analysis with two-loop β-functions and mass spectrum improved by radiative corrections can make the energy scale set more precise. Namely, the M_0 scale can be split to establish squark and slepton scales separately, while the energy scale hierarchies as two global classes should remain.

In this paper, the hierarchy $M_0 \gtrsim M_{1/2} \gg \mu$ (the Split Higgsino model) was considered in detail. In this case, the renormalization group approach determines the SUSY breaking scale as $M_{SUSY} \sim 10^8 - 10^9\,\mathrm{GeV}$.

Due to the degenerate mass spectrum of the lightest states in the model the coannihilation channels are essential for the effective annihilation cross section. With the calculated value of $< \sigma_{eff} v >$ the relic abundance value is provided by the lowest Higgsino mass in the interval $1.2\ -\ 1.6\,\mathrm{TeV}$.

Experimental observation of this scenario effects crucially depends on ΔM_{χ^0} and ΔM_{χ_c}. If these differences are $\sim 10\,\mathrm{GeV}$, products of χ_2^0 and $\chi^{\pm}$ decays can be, in principle, detected at the LHC, for small splittings these decay modes are invisible. At the same time, if superscalars are close to the lowest Higgsino scale, their specific manifestations are possible too. In particular, such squarks at a TeV scale should increase significantly the SI neutralino-nucleon cross section. Heavy scalars from the hierarchy $M_0 \gg \mu$ do not change the tree level $\chi - N$ cross section significantly.

Even if there are signals from neutralino and /or chargino decays, they are hardly detected. Despite these (possible) effects the Split Higgsino model is characterized by $\chi - N$ scattering with the small and therefore yet unregistered SI cross section and some typical value of a continuous annihilation gamma flux. For small ΔM_χ values the M_{SUSY} scale is evaluated as $\lesssim 10^{10}\,\mathrm{GeV}$ in agreement with the RG results leading to unobserved SI $\chi - N$ scattering.

Conclude, to detect some footsteps of the scenario, it is necessary to analyze correlation of all collider data, $\chi - N$ cross section measurements and value of diffuse gamma flux from halo (or direct photon spectrum). Only a comparison of all measured characteristics could give some conclusions on the scenario realization. In a sense, this model presents a class of “Hidden SUSY” scenarios which do not reject SUSY ideas and at the same time, can explain (possible) absence of obvious SUSY signals at the LHC.

If, however, the neutralino annihilation induced continuous gamma flux is not detected at all, simultaneously with the absence of neutralino and chargino decay modes at the LHC, it will mean that the DM origin cannot be understood in the MSSM framework. Then to explain the DM origin and properties there should be attracted some other sources, as gravitino, for example.

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